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SEVERAL BRAZE FILLER METALS FOR JOINING
AN OXIDE-DISPERSION-STRENGTHENED
NICKEL-CHROMIUM-ALUMINUM ALLOY

Charles A. Gyorgak

Lewis Research Center

Cleveland, Ohio 44135



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16. Abstract An evaluation was made of five braze filler metals for joining an aluminum-containing oxide dispersion-strengthened (ODS) alloy, TD-NiCrAl. All five braze filler metals evaluated are considered suitable for joining TD-NiCrAl in terms of wettability and flow. Also, the braze alloys appear to be tolerant of slight variations in brazing procedures since joints prepared by three sources using three of the braze filler metals exhibited similar brazing characteristics and essentially equivalent 1100° C stress-rupture properties in a brazed butt-joint configuration. Recommendations are provided for brazing the aluminum-containing ODS alloys.			
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SEVERAL BRAZE FILLER METALS FOR JOINING AN OXIDE-DISPERSION-STRENGTHENED NICKEL-CHROMIUM-ALUMINUM ALLOY

by Charles A. Gyorgak

Lewis Research Center

SUMMARY

An evaluation was made of five braze filler metals for joining an aluminum-containing oxide dispersion-strengthened alloy, TD-NiCrAl. Both T-joint and butt-joint specimens were used in the evaluation which included filler metal wettability and flow, remelt temperature, and the 1100° C stress-rupture strength of butt joints. In conducting this evaluation brazed samples were made by three sources to provide a comparison of vacuum brazing procedures and to assess reproducibility of three of the filler metals evaluated (TD-6, B-2, and NASA-18).

All five filler metals evaluated are considered suitable for brazing TD-NiCrAl. They are TD-6, B-2, NASA-18, NASA-21, and NASA-22. Also, brazed joints prepared by three sources using the TD-6, B-2, and NASA-18 filler metals exhibited similar brazing characteristics for the same filler metal in terms of wettability, flow, and remelt temperature even though slightly different brazing procedures were used by each source. Also, 1100° C stress-rupture properties of brazed butt joints produced by the three sources were similar. Butt joints brazed with the NASA-22 filler metal exhibited about 50 percent greater stress-rupture strength for times up to 300 hours. Beyond 300 hours all butt-joint assemblies were essentially equivalent in stress-rupture strength.

INTRODUCTION

Oxide dispersion-strengthened (ODS) Ni-Cr alloys are of interest for applications such as aircraft turbine engine components and have been considered for re-entry heat shields for space vehicles (refs. 1 and 2). Joining these materials by conventional techniques has presented some problems in achieving good high-temperature joint properties. For example, fusion welds destroyed the wrought properties of the alloys and

caused failure to occur in the nugget or weld region of the joint at relatively low stresses (refs. 3 and 4).

Diffusion welding techniques have been developed (refs. 5 and 6) which produce joints having parent metal properties. However, with the variety of shapes that might be required for present and future applications, the use of diffusion welding might be limited. For the more complex joint configurations, brazing offers good potential. A brazing filler metal TD-6 (Ni-15Cr-4W-16Mo-4.5Si-6Fe) was developed for joining the ODS-NiCr alloy TD-NiCr (ref. 7). Improved filler metals were subsequently developed for TD-NiCr that were less reactive and exhibited better joint strength (refs. 8 and 9). These filler metals were identified as B-2 (Ni-20Cr-30Mo-6Si-4Al) and NASA-18 (Ni-16Cr-15.6Mo-4.5Si-8.6Al).

The more recent ODS alloys contain aluminum for improved oxidation resistance (ref. 10). These alloys (such as TD-NiCrAl, IN MA953, and Haynes developmental alloy 8077) have a high alumina-containing protective oxide scale, which could lead to difficulties in brazing, primarily in wetting and flow of the braze filler metals.

The purpose of this study was to evaluate the potential of several filler metals for brazing one of the aluminum-modified ODS alloys TD-NiCrAl (Ni-16Cr-4Al-2ThO₂). Three filler metals developed for TD-NiCr (TD-6, B-2, and NASA-18) and two new filler metals (NASA-21 and NASA-22) formulated for the aluminum modification were used in this evaluation. The five braze filler metals were evaluated for joining TD-NiCrAl in terms of wettability, flow, reactivity, and 1100° C stress-rupture life of brazed butt-joints.

In conducting this evaluation, brazed samples were made by three sources to provide a comparison of vacuum brazing procedures and to assess reproducibility of three of the filler metals included in the study for brazing TD-NiCrAl. From the overall results of this evaluation, some recommendations are made for brazing aluminum-containing ODS alloys.

EXPERIMENTAL PROCEDURE

Materials

The TD-NiCrAl sheet used for this evaluation came from two heats, one 0.038 centimeter thick and one 0.127 centimeter thick. Both heats were supplied (by Fansteel, Inc.) in the recrystallized condition. The chemical analyses of the specimen materials are given in table I. Details of the sheet manufacture are given in reference 10.

The filler metals were produced by a commercial source (Alloy Metals, Inc.) in the form of prealloyed powders to NASA specifications. These alloys were atomized, cleaned, and separated into two particle size fractions: a plus 325 mesh fraction and a

minus 325 mesh fraction. Only the minus 325 mesh fraction was used in this brazing study. The chemical analyses and flow points of the filler metal powders are given in table II.

Brazing Procedure

Wettability, flow, reactivity of the filler metals, and braze remelt temperatures were determined on T-joint specimens shown in figure 1(a). Stress-rupture life of brazed assemblies was determined on butt-joint specimens shown in figure 1(b).

Reproducibility of brazing characteristics was determined by evaluating T-joint and butt-joint specimens brazed by two commercial sources. For this evaluation brazements were made by Solar Division of International Harvester Company and by Wall Colmonoy Corporation using the filler metals TD-6, B-2, and NASA-18.

The sheet material used by NASA and Wall Colmonoy was processed for brazing by NASA as follows: (1) machine sand surfaces of the TD-NiCrAl sheet to remove oxides formed during the recrystallization heat treatment (ref. 10); (2) shear sheet material to specimen size; and (3) grind faying surfaces flat and parallel as required for brazing. After grinding, the specimen sections were cleaned ultrasonically to remove grinding and handling residues as follows: (1) washed with trichlorofluorethane (freon), (2) washed with acetone, (3) washed with ethanol, and (4) washed with distilled water. All samples were stored in freon until assembled for brazing. The as-received sheet supplied to Solar required surface preparation before brazing could be accomplished. Details of the brazing procedures used by the three sources are outlined in the following sections.

NASA. - T-specimens and butt-joint specimens were assembled and tack welded (as indicated in fig. 1) to keep faying surfaces in proper position during brazing. Braze filler metals were preplaced on one side as a slurry in a carrier of acetone-thinned-acryloid-cement. In addition to the three filler metals evaluated by all sources, T- and butt-joint specimens brazed with the NASA-21 and NASA-22 filler metals were included in this part of the study.

All brazing was accomplished in a vacuum furnace at pressures ranging from 0.066 to 0.133 pascal. Temperature was measured with the aid of a QR (platinum, platinum - 13 percent rhodium) thermocouple in contact with the braze specimen and recorded on a strip chart. No postbrazing cleaning was required.

Solar. - Solar sheared the sheet material to specimen size and then ground the opposed sheared edges, which would become the faying surfaces, flat and parallel. The large T-joint specimen surfaces were hand sanded to remove the oxidized layer. The specimen assemblies were tack welded with nickel straps to maintain alignment during brazing. Braze filler metals were applied to one side of the joint as a slurry in standard

Solar Organic Binder P13-42. Brazing was accomplished in a vertical vacuum furnace at pressures ranging from 0.006 to 0.013 pascal. Brazing temperature was determined using a micro-optical pyrometer. All specimens were glass-bead blasted and then ultrasonically cleaned after the braze cycle was completed.

Wall Colmonoy. - Wall Colmonoy cleaned the sheared sheet material by solvent degreasing and then tack welded the specimen assemblies (fig. 1) in order to maintain alignment during brazing. The braze filler metal was applied as a bead on one side of the specimen only. Brazing was accomplished in a vacuum furnace at pressures ranging from 0.013 to 0.066 pascal. Temperature was determined by the use of QR thermocouple and reported as "slightly above the liquidus for each filler metal." No postbrazing cleaning of the assemblies was deemed necessary.

Evaluation Procedure

The evaluation of all brazed samples was conducted at the Lewis Research Center using the procedures outlined in this section. All brazed specimens were given a post-braze diffusion anneal for 16 hours at 1200⁰ C before testing. This anneal was given to improve homogeneity of the braze filler metals and parent metals in wide gap areas (ref. 8).

The T-joint and butt-joint specimens were sectioned, and test-grip holes were provided (as shown in fig. 1) before the diffusion annealing treatment. This was done to provide as-brazed and brazed-diffusion-annealed specimens for metallographic evaluation and diffusion-annealed specimens for mechanical testing. T-specimens were sectioned with an abrasive saw, and the butt-joint specimens were sectioned by electrical discharge machining (EDM).

Wettability and flow. - Wettability and flow of the braze filler metals on the TD-NiCrAl were evaluated visually by macroscopic and microscopic inspection. Standard metallographic techniques were used to determine the morphology of the brazed joints in both the as-brazed and brazed-diffusion-annealed conditions.

Remelt temperatures. - Remelt temperatures for each braze filler metal were determined on T-joint specimens in an induction heated furnace (see fig. 2). The braze area (thickness \times length of specimen, neglecting any fillet) was stressed at 0.7 megapascal, and the temperature was determined with a QR thermocouple and recorded on a strip chart. When the specimen under test failed, the weight used to produce the stress fell into the tray (fig. 2) and pulled the thermocouple off the specimen. The highest temperature recorded was taken as the "remelt" temperature. The average heating rate was 50⁰ C per minute.

Stress-rupture tests. - Stress-rupture lives of butt-joint specimens were determined in conventional 1:1 ratio lever-arm stress-rupture machines. Butt-joints were

evaluated at stresses ranging from 34.5 to 13.8 megapascals at a temperature of 1100⁰ C. For the butt-joint specimens the effects of the fillets were neglected in calculating the applied stress in all of the tests.

RESULTS AND DISCUSSION

Wettability and Flow

Macroscopic and metallographic evaluation of brazed joints indicated that all the braze filler metals wet the parent metal TD-NiCrAl (figs. 3 and 4). Some variations in the amount of braze and size of braze gap existed in the specimens produced by the three sources. Solar used the least amount of braze (about 0.02 g/cm) and NASA the most (about 0.04 g/cm). Braze gaps (clearances) varied from specimen to specimen and ranged from 0.0015 to 0.007 centimeter. The wide gaps were typical, and fillets on each side of these joints were approximately equal. When the gap between faying surfaces were approximately 0.0015 cm, the braze filler metal would fill the gap, but would not fillet equally on the side opposite the placement of the braze (figs. 3(c), 4(b), and 4(e)). Thus, variations in the degree of braze flow were more dependent on the amount of braze used and joint gap variations rather than any single characteristic of the filler metals.

Typical microstructures of T-joints in the as-brazed and as-brazed-diffusion-annealed conditions (fig. 4) show the degree of homogenization and filler metal reaction with TD-NiCrAl. With the 16-hour diffusion anneal at 1200⁰ C, the greatest degree of homogenization occurred in assemblies brazed with NASA-21 and NASA-22.

The most reactive filler metal was NASA-21 (fig. 4(d)). More parent metal cross section reacted with a given amount of filler metal than occurred with any of the other four filler metals. Since the only major difference in NASA-21 and NASA-18 is the substitution of tungsten for molybdenum, this observation suggests that the high silicon and aluminum filler metals containing tungsten are more reactive with TD-NiCrAl.

Remelt Temperatures

The remelt temperatures of the brazed T-joints stressed at 0.7 MPascal are given in table III, along with the brazing temperature reported by each brazing source. The remelt temperatures for TD-6 and NASA-21 were above the brazing temperature. The B-2 test specimens failed through the pin hole or the braze-affected zone at temperatures below the brazing temperature; NASA-18 braze filler metal failed in the braze at remelt temperatures near the brazing temperature. The failure in NASA-22 brazed

specimens occurred in either the loading-pin-hole or the braze-affected zone at temperatures below the brazing temperature.

As shown in table III both the B-2 and NASA-22 remelt tests were considered atypical since the failures did not occur in a liquid phase at the faying surfaces. The remelt temperatures for the same filler metals were generally in good agreement among the samples provided by the three braze sources.

Stress-Rupture Properties of Brazed Butt-Joints

Metallographic sections of typical as-brazed and brazed-diffusion-annealed butt-joint stress-rupture specimens are shown in figure 5. On the average, braze gaps (clearances) were greater in the butt joints of the stress-rupture specimens than those encountered in the T-joint specimens. The maximum gap in the T-joint specimens was of the order of 0.007 centimeter; whereas, the maximum gap in the butt-joint stress-rupture specimens was of the order of 0.016 centimeter.

Diffusion annealing caused some homogenization of the braze filler with the greater amount occurring in the NASA-22 brazements. The 1100⁰ C stress-rupture lives of diffusion-annealed brazed butt joints are given in table IV and plotted in figure 6.

Among the braze sources, some variations in stress-rupture life occurred in each filler metal brazed joint (table IV). However, regardless of brazing source, the stress-rupture lives of brazed joints prepared with TD-6, NASA-18, and B-2 were in a rather narrow range, as indicated in figure 6. This grouping tendency appears to indicate that each braze source produced essentially equivalent brazed butt joints in TD-NiCrAl with a rupture strength of approximately 21 megapascal for a 100-hour life at 1100⁰ C. This grouping tendency also indicates that the braze filler metals are tolerant of the slight variations in brazing procedures used.

A least-means-squares analysis of the stress-rupture data was made for each braze filler metal; the results are shown in figure 7. The data for the four filler metals TD-6, B-2, NASA-18, and NASA-21 fall within a narrow band. The stress-rupture life curves of TD-6, B-2, and NASA-18 have approximately the same slope, and NASA-21 produced a stress-rupture life curve that is relatively flat from 1 to 1000 hours. Joints brazed with NASA-22 filler metal produced values approximately 50 percent greater in rupture strength than the other alloys for times from 60 to about 300 hours. Beyond 300 hours, there was no significant difference in the rupture strength of butt joints made with the five braze filler metals.

CONCLUSIONS

Based on an investigation of joining TD-NiCrAl by brazing techniques using five braze filler metals, the following conclusions are made:

1. All five braze filler metals (TD-6, B-2, NASA-18, NASA-21, and NASA 22) evaluated are considered suitable for brazing TD-NiCrAl.
2. The braze alloys appear to be tolerant of slight variations in brazing procedures. Brazed butt joints and T-joints prepared by three sources using the filler metals TD-6, B-2, and NASA-18 exhibited essentially equivalent brazing characteristics in terms of braze remelt temperature, reactivity, wettability, and flow.
3. The 1100⁰ C stress-rupture properties of brazed butt joints using the filler metals TD-6, B-2, and NASA-18 produced by three sources were essentially equivalent, having a rupture strength of about 21 megapascal for a 100-hour life. Butt joints brazed with the NASA-22 filler metal exhibited about 50 percent greater rupture strength than the other filler metals. However, this advantage was evident for times up to about 300 hours, beyond which all of the brazed butt joints had similar stress-rupture properties.

RECOMMENDATIONS

ODS-alloys containing aluminum must have clean metal surfaces when being brazed with filler metals that are not self-fluxing. Oxide films should be removed from the faying surfaces. Abrading the film at room temperature by machine sanding with a copious amount of coolant has been found to be most adequate.

Sanding or grinding residues and all oil and organic contaminants should be removed with solvents that will not leave residual films on the faying surfaces.

Cleaned specimens or assembly parts should be stored under solvents that will evaporate without leaving a residual film.

If organic binders are used for placement of powder braze filler metals, heating should be slow until all of the binder is volatilized to keep the binder from expelling the braze metal from its preplaced site.

Rapid heating from binder volatilization to brazing temperature is suggested. A hold time at liquation temperature to assure complete flow of braze filler metal into the joint is recommended. Cooling rate for this system of alloys is not critical: cool as rapidly as the vacuum furnace facility will permit.

For high temperature service braze filler alloys with the highest flow temperatures are preferred providing that they are compatible with structural applications of the assemblies.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 27, 1975,
505-01.

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TABLE I. - CHEMICAL COMPOSITION OF TD-NiCrAl SHEETS

Heat number	Thick-ness, cm	Composition					
		Nickel, wt %	Chromium, wt %	Aluminum, wt %	Thoria, wt %	Carbon, ppm	Sulphur, ppm
3905-4	0.038	Bal.	17.6	3.7	2.1	418	43
3927	.127	Bal.	17.4	4.6	2.1	340	25

TABLE II. - ACTUAL COMPOSITIONS AND FLOW POINTS
OF BRAZE FILLER METALS

Filler metal	Composition ^a , weight percent							Approximate flow temperature, ^b °C
	Chromium	Tungsten	Molybdenum	Silicon	Aluminum	Iron	Nickel	
TD-6	15.1	4	15.9	4.5	---	6.1	Bal.	1265
B-2	19.8	----	30.1	.6	4.2	---	↓	1288
NASA-18	15.9	----	15.6	4.5	8.6	---	↓	1280
NASA-21	16.4	12.6	----	5.4	7.0	---	↓	1260
NASA-22	15.9	15.5	----	1.9	4.3	---	↓	1320

^aVendor analysis.^bAs determined by NASA.TABLE III. - BRAZE AND REMELT TEMPERATURES OF
BRAZE-FILLER-METALS FOR TD-NiCrAl T-JOINTS

Braze filler metal	Brazing performed at -					
	Solar		Wall Colmonoy		NASA Lewis	
	Temperature, °C					
	Braze	Remelt ^a	Braze	Remelt ^a	Braze	Remelt ^a
TD-6	1293	1345	>1265	1320	1280	1345
B-2	1300	^b 1093	>1288	^c 1254	1300	^b 1110
NASA-18	1293	1260	>1300	1280	1304	1295
NASA-21	----	-----	-----	-----	1290	1320
NASA-22	----	-----	-----	-----	1335	^c 1310 ^b 1325

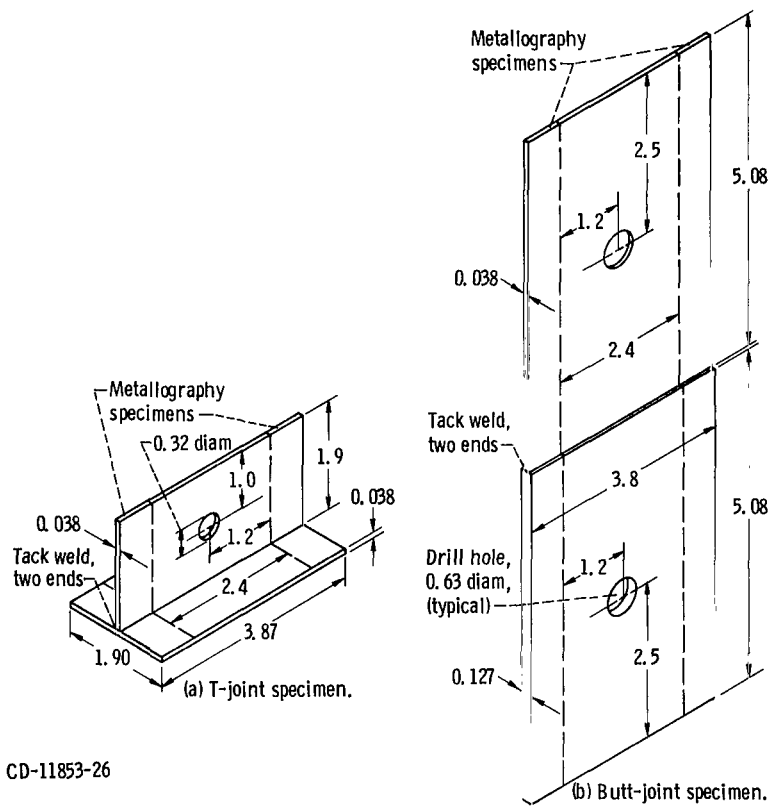
^aBrazed T-joints were diffusion-annealed 16 hours at 1200° C before test and stressed 0.7 M Pa during testing.^bLoading-pin hole failure.^cBraze affected zone.

TABLE IV. - STRESS-RUPTURE LIFE OF BRAZED TD-NiCrAl BUTT-JOINTS AT 1100° C.

ALL SAMPLES DIFFUSION ANNEALED 16 HOURS AT 1200° C BEFORE TESTING

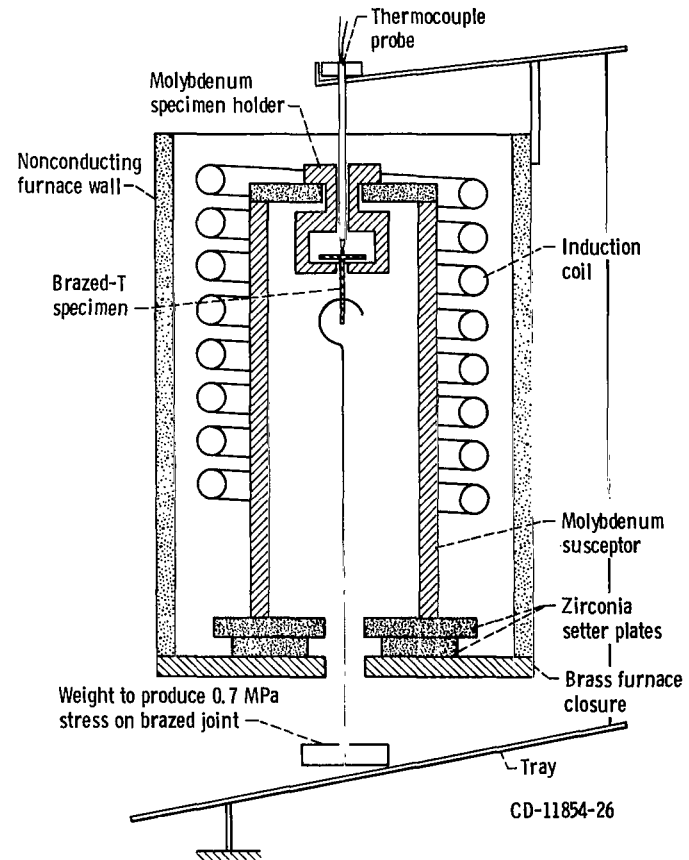
Braze filler metal	Brazing performed at -	Amount of filler metal ^a , g/cm	Braze temperature, °C	Stress		Life, hr	Remarks
				MPa	ksi		
TD-6	NASA	0.06	1270	34.5	5.0	0.2	Braze failure
		.05	1290	34.5	5.0	1.4	
		.03	1280	20.7	3.0	4.5	
	Solar	.02	1290	34.5	5.0	.6	
		.02	1290	20.7	3.0	2.0	
	Wall Col-monoy	ND ^b	ND	34.5	5.0	2.2	
		↓	↓	24.1	3.5	7.0	
				20.7	3.0	44.5	
				20.7	3.0	137.3	
B-2	NASA	0.04	1295	34.5	5.0	1.0	Braze failure
		.05		34.5	5.0	33.8	
		.04		20.7	3.0	189.3	
		.02		↓	↓	662.2	
		.01	1305	↓	↓	786.0	
		.01	1305	↓	↓	1485.9	
	Solar	.02	1300	↓	↓	152.3	Stopped test
		↓	1300	↓	↓	333.9	
		↓	1300	13.8	2.0	262.7	
	Wall Col-monoy	ND	ND	34.5	5.0	20.3	Braze failure
		↓	↓	20.7	3.0	30.7	
				↓	↓	97.7	
				↓	↓	110.7	
				↓	↓	211.9	
NASA-18	NASA	0.05	1310	34.5	5.0	1.9	Braze affected zone
		.02	1300	34.5	5.0	1.9	Braze affected zone
		.03	1290	24.1	3.5	61.3	Braze affected zone
		.07	1310	20.7	3.0	27.1	Braze failure
		.05	1305	↓	↓	64.1	Braze affected zone
		.04	1310	↓	↓	72.8	↓
		.10	1310	↓	↓	220.4	
		↓	↓	↓	↓	↓	
	Solar	.02	1280	↓	↓	139.8	↓
		↓	↓	↓	↓	236.7	
	Wall Col-monoy	ND	ND	34.5	5.0	353.5	Stopped test
		↓	↓	↓	↓	402.1	Braze affected zone
				34.5	5.0	6.9	Braze failure
				27.6	4.0	.6	
				20.7	3.0	11.4	
				20.7	3.0	21.1	
NASA-21	NASA	0.11	1270	34.5	5.0	1.1	Braze failure
		.07	1270	34.5	5.0	2.5	Braze affected zone
		.09	1260	27.6	4.0	4.8	Braze failure
		.10	1260	20.7	3.0	.1	Braze failure
		.06	1295	↓	↓	26.2	Braze affected zone
		ND	1290	↓	↓	118.0	Braze failure
		.01	1290	↓	↓	218.5	Braze failure
NASA-22	NASA	0.08	1340	34.5	5.0	143.4	Pin hole failure
		.08	1330	27.6	4.0	61.1	Braze failure
		.09	1320	20.7	3.0	425.9	Stopped test
		.13	1330	20.7	3.0	507.2	Braze failure

^aGrams of filler metal used per centimeter of length of brazed joint.^bNot determined.



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Figure 1. - Isometric sketches of brazing specimens evaluated. (Dimensions are in cm.)

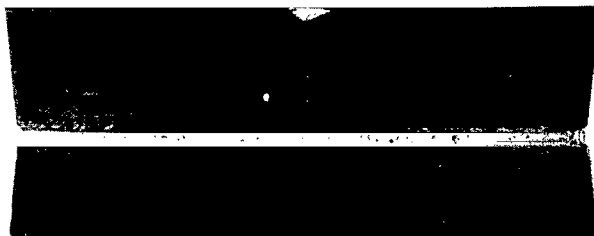
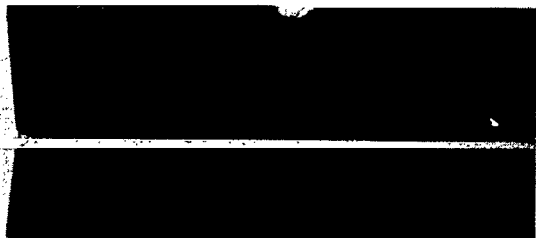


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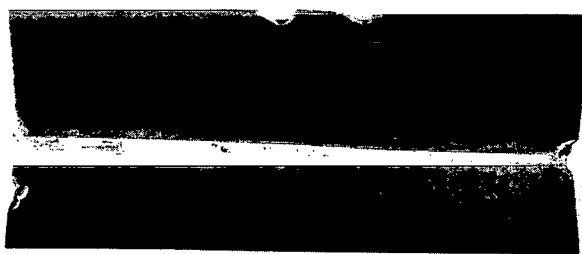
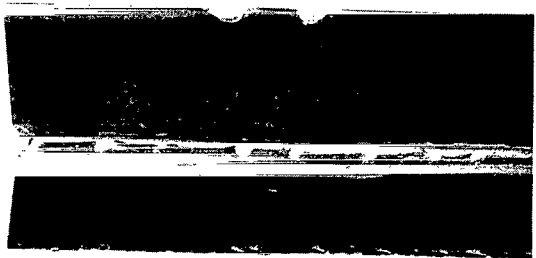
Figure 2. - Furnace test assembly for determining braze remelt temperature.

Braze application - side view

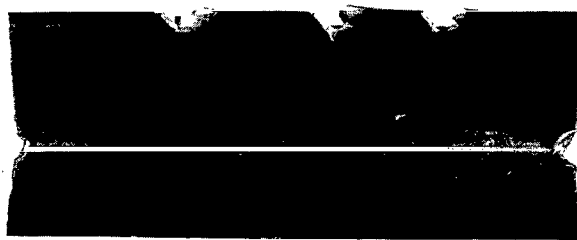
Braze penetration - opposite side



(a) Braze material TD-6.



(b) Braze material B2.

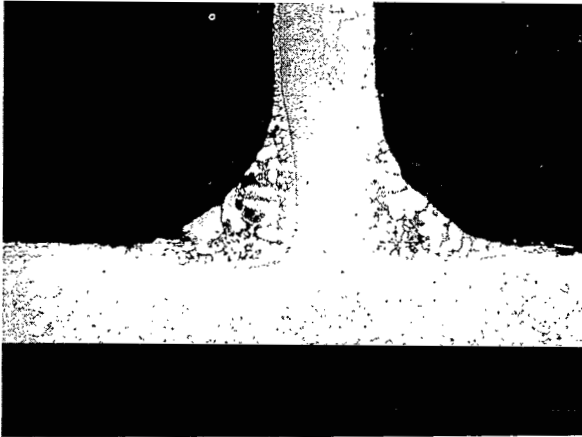


(c) Braze material NASA-18.

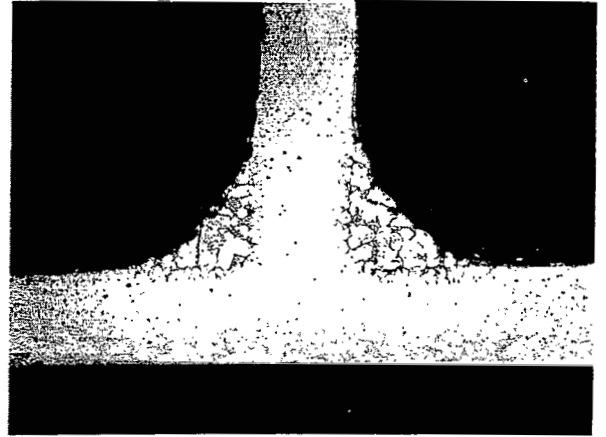
0.5 cm

Figure 3. - Typical wetting and flow of braze filler metals on TD-NiCrAl T-joints. Unetched.

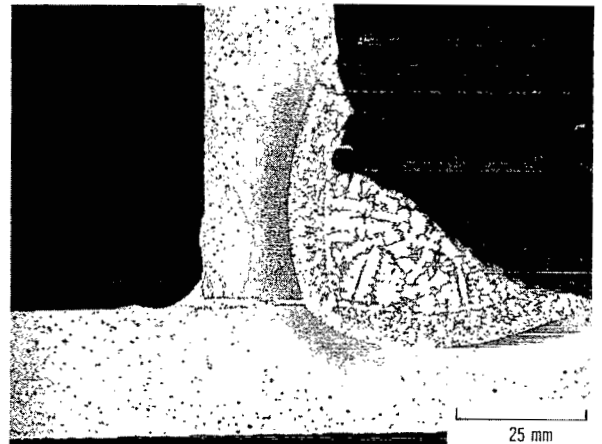
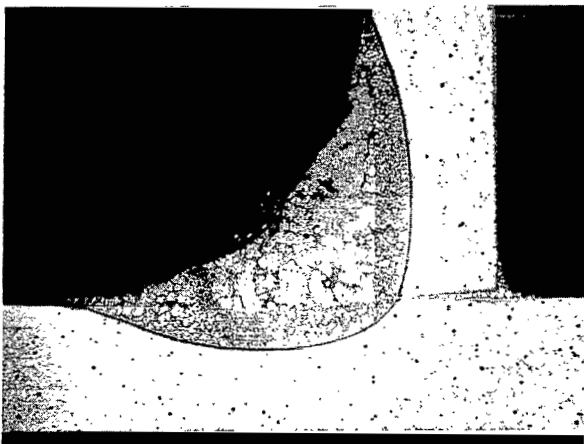
As brazed



Diffusion annealed



(a) Braze material, TD-6.

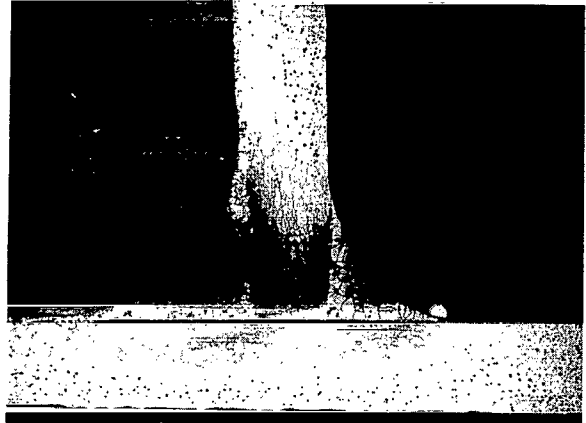
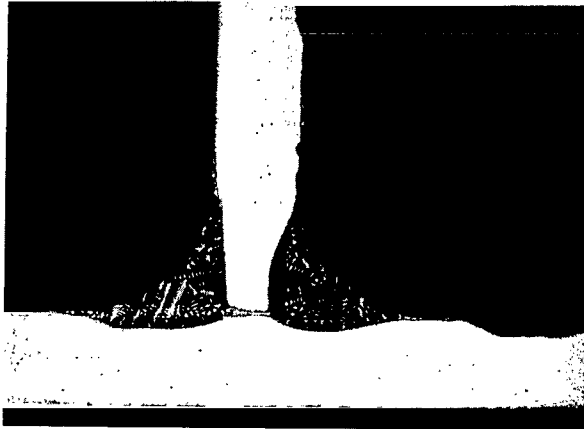


(b) Braze material, B2.

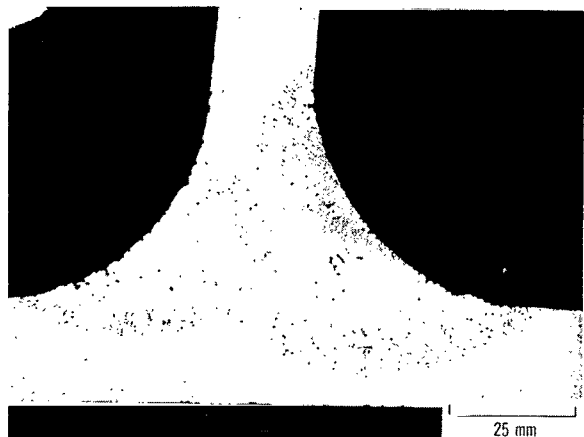
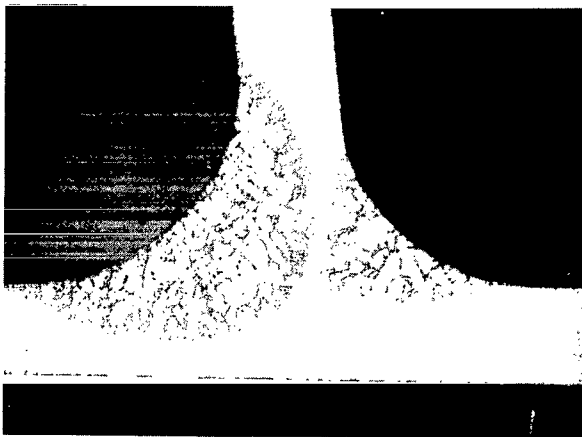
Figure 4. - Microstructures of typical brazed T-joint specimens. Diffusion anneal conditions: 16 hours at 1200° C. Electrolytically etched. Etchant: 20 parts water, 20 parts glycerol, 10 parts nitric acid, 5 parts hydrofluoric.

As brazed

Diffusion annealed

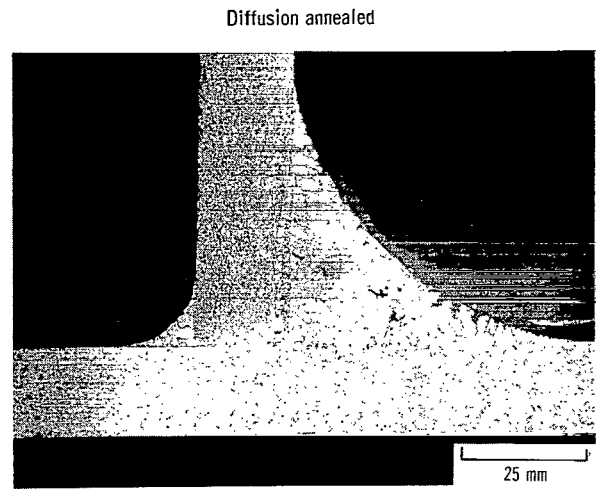
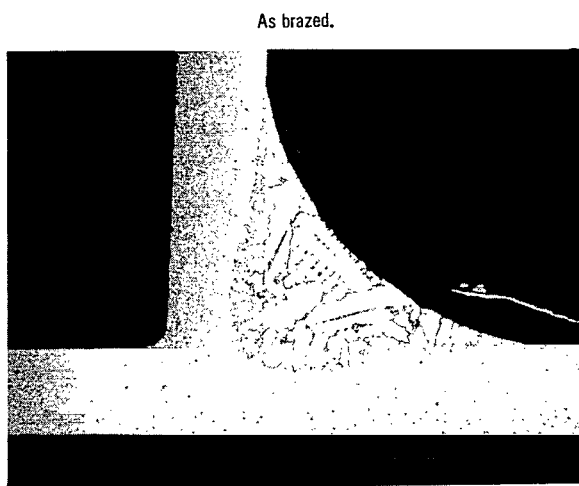


(c) Braze material, NASA 18.



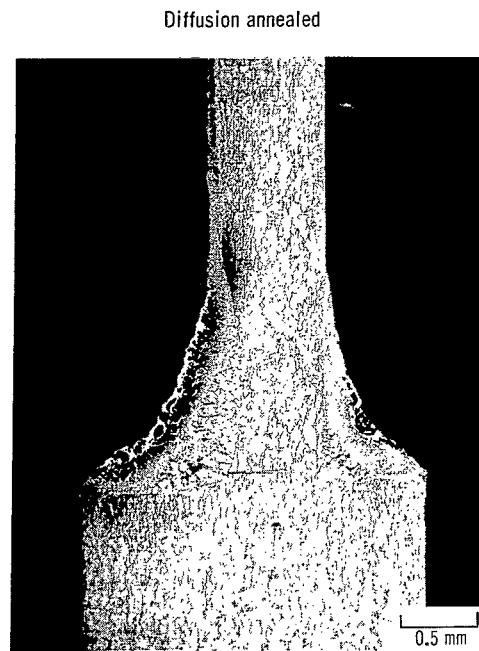
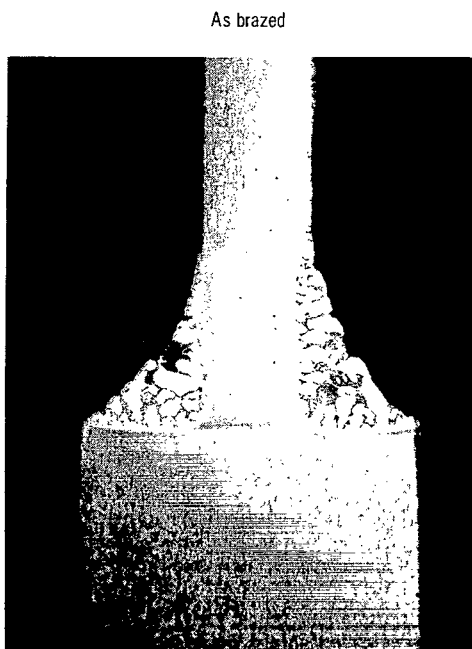
(d) Braze material, NASA 21.

Figure 4. - Continued.



(e) Braze material, NASA 22.

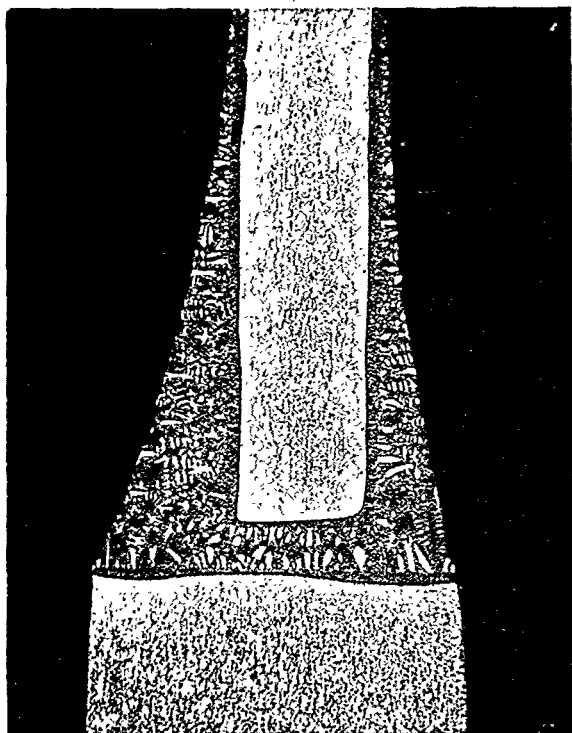
Figure 4. - Concluded.



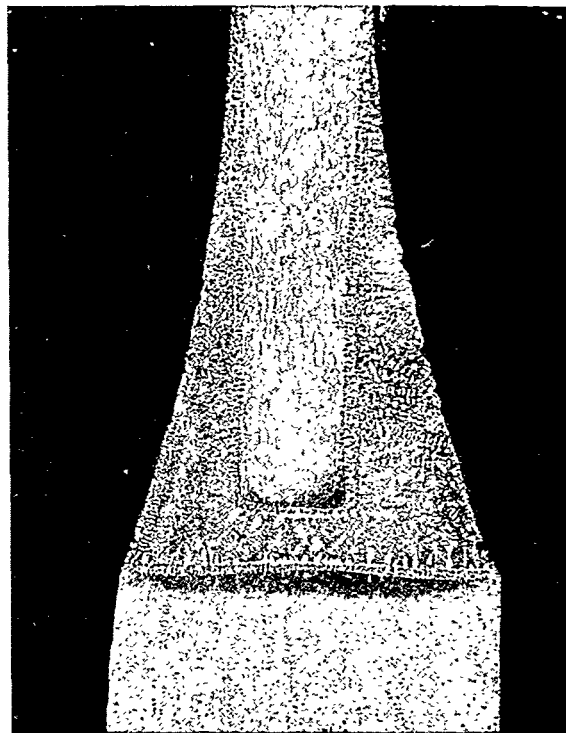
(a) Braze material, TD-6.

Figure 5. - Microstructures of typical brazed butt-joint specimen. Electrolytically etched; etchant: 20 parts water, 20 parts glycerol, 10 parts nitric acid, 5 parts hydrofluoric acid. Diffusion anneal conditions, 16 hours at 1200° C.

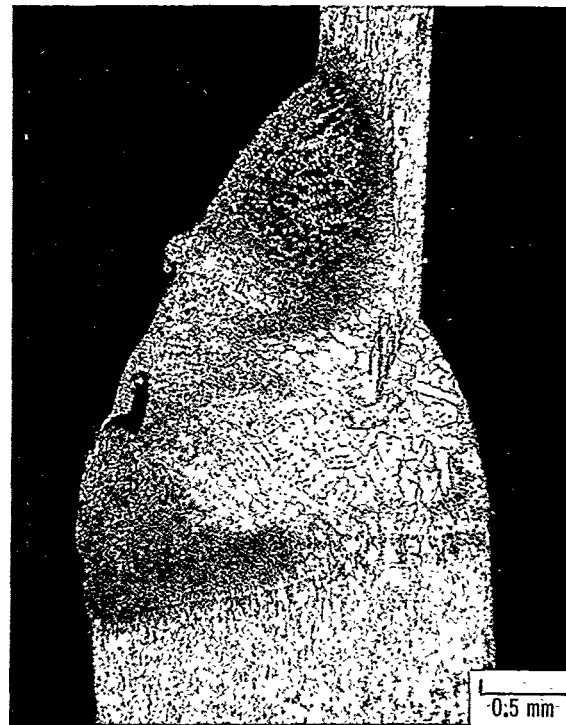
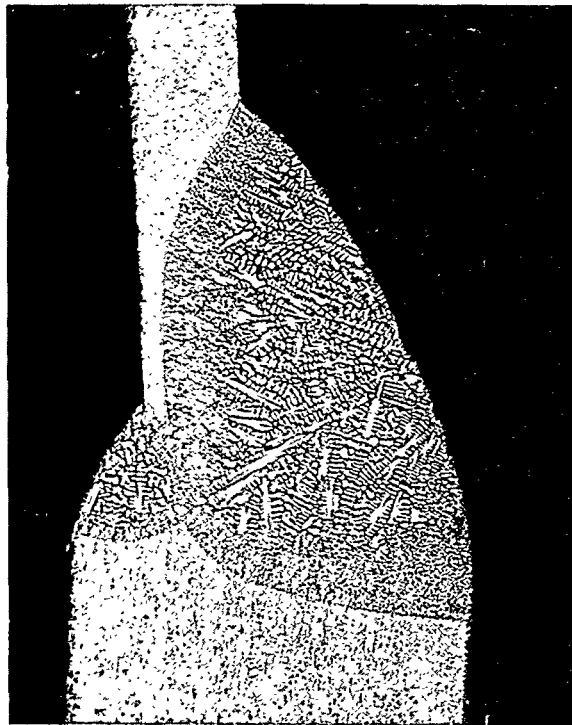
As brazed



Diffusion annealed



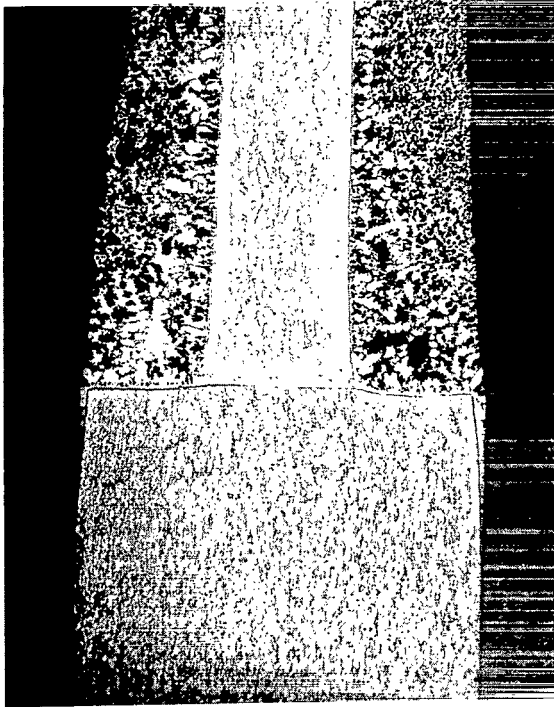
(b) Braze material, B-2.



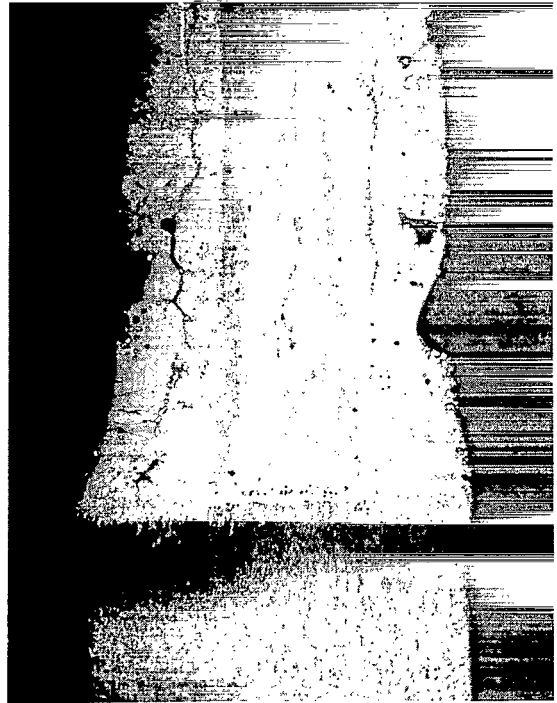
(c) Braze material, NASA 18.

Figure 5. - Continued.

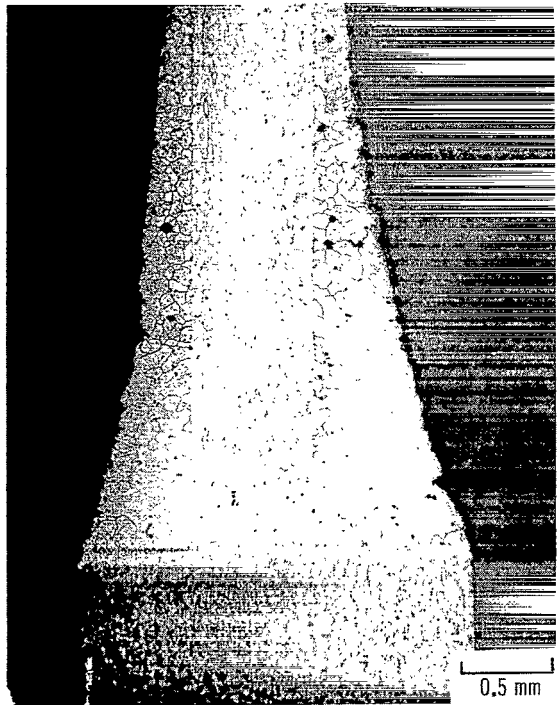
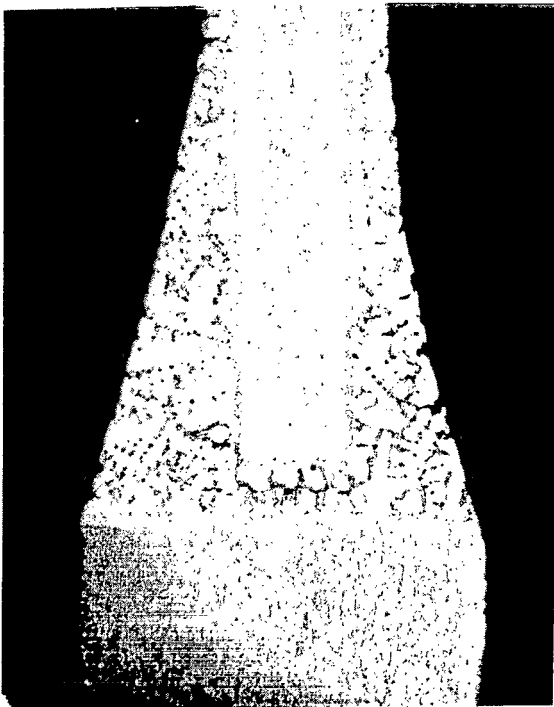
As brazed



Diffusion annealed



(d) Braze material, NASA 21.



(e) Braze material, NASA 22.

Figure 5. - Concluded.

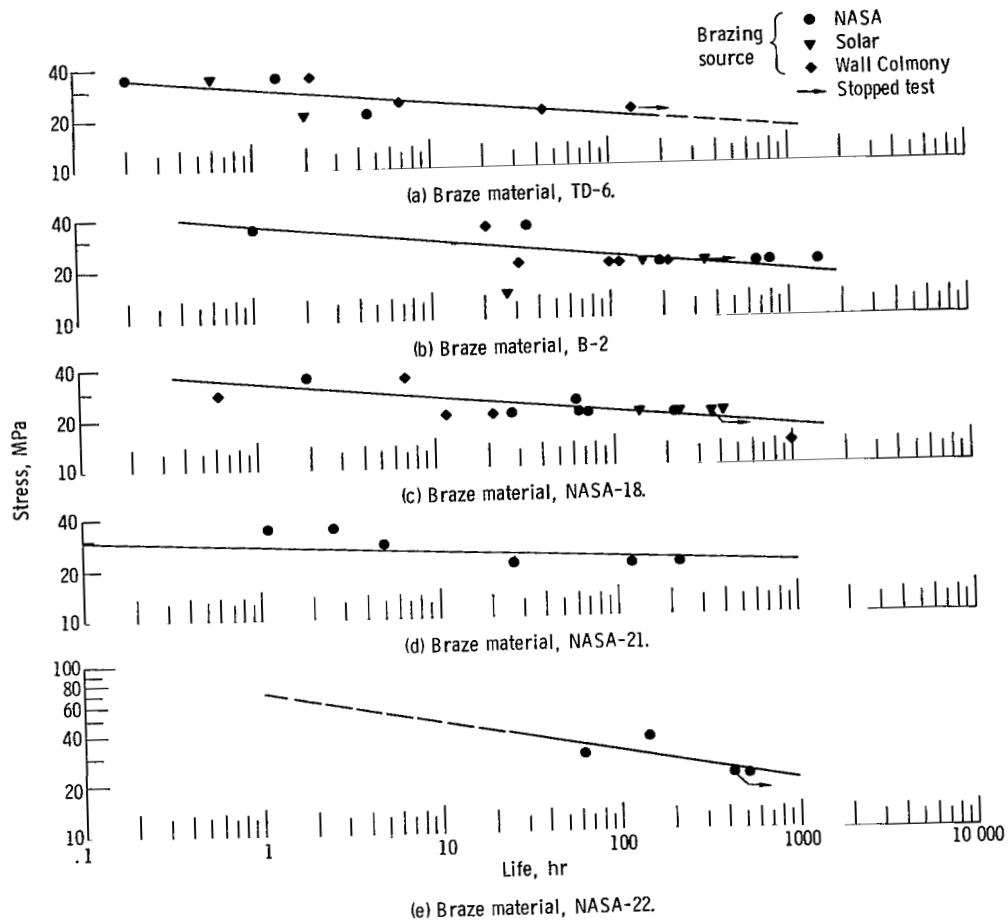


Figure 6. - 1100°C stress-rupture lives of TD-NiCrAl brazed butt joints. All samples diffusion annealed 16 hours at 1200°C before testing.

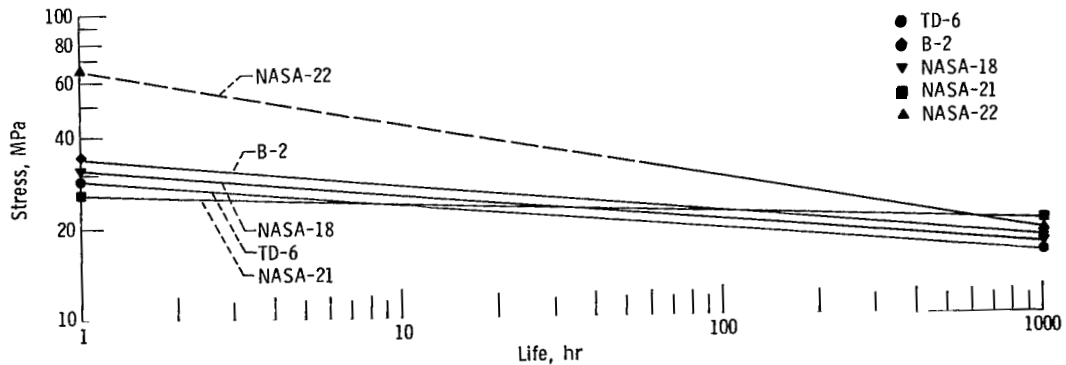


Figure 7. - 1100°C stress-rupture lives of TD-NiCrAl brazed butt-joints based on least-means-square analysis.



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